Chapter 11:

THE ARCHITECTURE OF ASSEMBLY:

INDUSTRIALIZATION AND RATIONALIZATION OF THE DESIGN PROCESS

I. THE FACTORS SURROUNDING THE INDUSTRIAL REVOLUTION AND CREATION OF THE INDUSTRIALIZED WAY OF THINKING:

The industrial revolution is characterized by certain basic changes which occurred first in England, from the middle of the eighteenth century onwards and which were evident, sooner or later, in the other countries of industrial production and the mechanization of productive systems (Benevolo p. xix)

The causes of the industrial revolution were basically threefold (Frampton: Modern Architecture)

1. CHANGE IN CULTURE: increase in man's capacity to exercise control over nature; lifestyle of rising bourgeoisie; historicist mode of thought, combined with increased travel and visitation of antique sites; population explosion.

2. CHANGE IN URBAN FORM: population explosion caused densification of city; problems with waste and pollution and inability of city form to handle this type of expansion caused a new look at town planning and subsequent reform of the existing cities--creation of ideal industrial towns

3. CHANGE IN TECHNOLOGICAL KNOWLEDGE: industrial revolution altered building techniques causing traditional materials to be worked in a more profitable way; new materials such as glass, cast iron and concrete (manufactured or processed); ability to calculate strength; accurate plans; training schools; division of design labor into the roles of architect and engineer

There were increasingly more types of industry, more products and processes for producing them. There was insufficient population to maintain traditional craft based production, so industrialized processes were needed to keep up with the demand for products. There was a fury of innovation -- invention and use of patents. There was an increase in quantities: larger facilities; more population meant more homes were needed and required to be built faster to keep up with demand. Economics changed: buildings were no longer meant to last forever so there followed a severance of the value of land and building. There was new potential in the site in view of transformations.

There was a distinct division of architectural design and engineering design. The field of knowledge had become so broad that it was difficult to maintain expertise in every aspect of the field.

The perfection of stereometry and mensuration processes heightened the speed and accuracy possible in geometrical investigations-- architects now had the ability to draw difficult or complicated figures. This enhanced the capabilities of communication between the designer and the constructor. The industrial production of bricks and timber allowed for the manufacture of greater quantities of these materials. By 1836 the production of the iron H section made use of iron for floor support more wide spread. There followed a reduction in prices of building supplies along with a raising of the wages of poor workers. This brought newer materials into traditionally poorer, low quality housing.

Style and Materiality:

The Enlightenment of the 18C demanded a look at the principles of architectural design in the light of reason and denied the previous universality of the rules of classicism. The debate of architectural style centered on the problem of eclecticism vs. rationalism. The architecture of the 19th century seemed to qualify an anything goes attitude with respect to the question of style. (classical, neo-gothic, neoclassical, etc. due to widespread study of and interest in other styles and histories of architecture vs. rationalism). It was a period of rapid change, reassessment and the learning connected with experimentation with new materials. The choices were based on objective reasons that could be rationally demonstrated--but architects in general were still unable to go beyond the pedagogy of the styles with which they were familiar.

There was an attack by Viollet-le-Duc on L'Ecole des Beaux Arts and its tradition of classicism. Viollet-le-Duc advocated Neo-Gothic as rationalist because of the clarity of its construction--(exposed structure). These became the ideas that led to the development of Art Nouveau towards the end of the 19th century.

Neoclassicism followed by Structural Rationalism as practiced by Labrouste. A style based on rationalism surfaced. This pedagogy centered on the design architecture that was based on true functions and respect for the materials used. It was significant that a substantial amount of cast and wrought iron was by this time in use in building -- which brought significant questions to the development of architectural theories.

The new structural movement centered on the insistence of the primacy of structure and on the derivation of all ornament from construction. Structural Classicism emphasized structure; the essence of the architecture is construction and all stylistic transformations are merely the logical consequence of technical development. This included the introduction of completely new concepts into building techniques, and the integration and use of iron and glass as principle materials, rather than secondary. Cast iron was originally used as secondary structural support in buildings. It was originally developed and used extensively in bridge construction. This period finally used cast (and wrought) iron as the primary structure in architecture. Cast iron columns and girders formed the skeleton of many industrial buildings and made it possible to roof large spaces with relatively slight and more fireproof structures. The development of the British Iron Industry was far ahead of the continental industry. Additionally the scope and capabilities of the glass industry was growing: panes of 2.5 m x 1.7 m were finally possible during the 1800's. Developments in 1836 culminated in the production of the iron H section. This made use of iron for floor support more wide spread.

II. NAPOLEON AND THE EFFECTS OF THE REVOLUTION ON THE IRON INDUSTRY:

The 1789 Revolution brought a halt to building. There was no intercourse with England so the French could not learn from the English iron industry, which was more advanced. Napoleon encouraged the iron industry, holding expositions of iron technology in 1801, 1802 and 1806. He supported the newly formed engineering schools, such as the Ecole Polytechnique (Durand and Rondelet). He was primarily interested in iron for its use in weapons. Napoleon would only grant authorization for new forges if they were to use coke rather than charcoal (modernization). He preferred cast to wrought iron because of the increased decorative capabilities of this molded material.

Delon de Cesart et Dillon. Pont des Arts, Paris, 1803:
Designed a footbridge spanning the Seine in nine arches resting on stone piers 18.1 meters apart. Each arch is composed of 5 principal ribs 1.8 meters apart, supported on skewbacks. The ribs, which are of rectangular section, 16 centimeters thick are in two parts, joined at the summit. The principal ribs are reinforced by additional ribs, which radiate above each of the masonry piers to connect one major rib to another. Cast iron ties join the ribs together transversely, and struts connect the small arches to the principal arches. The fallacy of this design is that it imitated timber construction by subjecting the members to tension, rather than recognizing that cast iron worked much better in compression.

Louis Bruyere. Pont sur la Crou. Saint Denis 1808:

Francois Belanger. Dome of the Halles au Ble. 1807-11:
This structure was the result of a competition for the design of the dome to replace the former timber one which had been destroyed by fire in 1802. Cost 700,000 francs, seven times the original cost estimate. Based on the voissoir principle as proposed by De l'Orme. Composed of 51 arched meridians each in 5 sections, or voussoirs, joined end to end, and decreasing in depth toward the summit. Each voussoir resembles a short beam, with upper and lower ribs joined at several points along the web. Supported on a circular cast iron wall plate. The base of the ribs are 2.42 meters apart and are fastened to the stone piers by anchor bolts. Diameter of 39.26 meters. Compression ring of 11.25 meters diameter at summit supporting a lantern.

Passages des Princes. Paris, 1860:
Initial idea to access dense urban fabric. Glass covered streets. A few built under Napoleon in the early 1800's, many in the 1820's. By the mid century the designs had progressed to ensure

ideas of marketing and merchandising. Sometimes three stories but never more. Cast iron used for its decorative properties.

Travernier. Gallerie de Fer. 1829:
This building type was the precursor to the modern shopping center. Different from the passage in that it provided a multiple shopping experience in a single structure, however, the shops were separately owned and run.

III. DURAND AND THE ECOLE POLYTECHNIQUE:

JACQUES-NICHOLAS-LOUIS DURAND (1760-1834):

In the area of architectural theory and design, the stage at which "theoria" was transformed into a self referential instrument for the control of "praxis" is best exemplified by the writings of Durand. Durand's Precis de Lecons were the first solid teaching concerned with rationalization. In the Precis, Durand defined architecture simply as the art of composing and executing all private and public buildings. In order to avoid wasteful expense, architectural design had to follow closely totally rational and immutable rules.

Durand was the most important of Boullee's pupils. Durand's most important contribution to architecture was his two theoretical works: "Recueil et Parallele des Edifices de Tout Genre, Anciens et Modernes" of 1801, and "Precis des Lecons d'Architecture" of 1802 which summarized the content of his courses at the Ecole Polytechnique.

In the Precis, Durand defined architecture simply as the art of composing and executing all private and public buildings. And because architecture was the most expensive of all the arts, it should not be whimsical or guided by prejudice or routine. In order to avoid wasteful expense, architectural design had to follow closely totally rational and immutable rules. Hence, "architecture had no other objective than private and public usefulness, the conservation and happiness of individuals, families and society". Durand summarized the basic precepts of his value system: "In all times and places, the totality of man's thoughts and actions were generated by two principles: love of well-being and aversion to pain."

Buildings were to be convenient and economical. For a building to be convenient, it had to be solid, healthy and comfortable. To be solid, it had to be built with materials of high quality and proportioned with intelligence. To be healthy, it had to be placed on a well-chosen site. And to be comfortable, the forms and dimensions of its parts had to be "in the most precise possible relation" considering the use for which the building was designed. With regard to economy, Durand explained that simple and symmetrical geometrical forms were to be used. Although these forms were very similar in appearance to those used by other architects of the late 18th century, the reasons were different. Durand recommends the use of a circular instead of a square or rectangular plan for the simple reason that its perimeter is less. The more symmetrical, regular and simple a building is, the less it will cost. Economy thus prescribed the manner and means of buildings, forbidding all that which was not strictly necessary.

Durand felt that there was no relation between nature, the human body and architecture. He rejected the theories of Vitruvius, Abbe Laugier and many others. The mathematical framework of positivism that Durand brought to architecture rejected metaphor as a serious and legitimate form of knowledge. Only theories backed with scientific proof were relevant. The classical orders since really not based on human proportions could not be considered the essence of architecture. Decoration is foolishness and the cause of unnecessary expenditure.

Elsewhere in the Precis Durand explained that there were three kinds of forms and proportions in architecture (1) those derived from the nature of the materials and from the use of the objects in whose construction they were employed (2) the forms dictated by custom, like those found in ancient buildings; and (3) the simple and well-defined shapes that were preferred because they could be easily apprehended.

Durand provided simple recipes for the proportions of the orders but insisted that the numerical relations had nothing to do with beauty.

The objective of all theory for Durand, was to ensure the efficiency and economy of operations. In order to achieve this and to simplify architectural design, Durand taught his students the "mecanisme de la composition", which consisted in the use of a grid to solve the fundamental problem of disposition, or arrangement of the elements in plan. Columns were to be placed at intersections, walls on the axes and openings at the centres of modules. Durand showed how to apply this method to all parts of a building, and these parts would then be combined in a specific project. only in the case of Durand's mecanisme did the grid become an instrument whose sole value was as a tool in a technological process. The method was the theory.

Plan, elevation and section were considered the only drawings necessary for the communication of a building, perspective disregarded as too "emotional" and inaccurate. He eschewed the use of atmospheric effects, avoided shading and rejected watercolour, presenting his drawings a clear black and white engravings of fact.

IV. ADVANCEMENTS IN THE USE OF CAST IRON DURING THE EARLY 1800'S:

Henri Labrouste. (1801-1875) Cour de Cassation, 1824.
Rendered elevation and long section, and section through main courtroom. Won the Grand Prix of Rome in 1824. Studied at Ecole des Beaux Arts. Inspired by the work of Hittorf in the arguments of polychromy, was one of the first to argue that such structures had been brightly colored. Insisted on the primacy of structure and the derivation of all ornament from construction.

Reflect and compare the plans of Labrouste and the Ecole des Beaux Arts with the plans of Durand who was teaching at the time at the Ecole Polytechnique. The symmetrical influence of neoclassicism prepared architectural design for the requirements of modularity and repetition to make building designs that were appropriate for industrialized techniques.

Henri Labrouste. Biblioteque Ste. Genevieve. 1838-50:

Plans, elevation, cross section. Inspired by the author Victor Hugo who wrote on architecture in the first half of the 1800's. He argued "Ceci tuera cela"; i.e. this will kill that, of the relationship between the printing press and architecture. Labrouste formed his own atelier in 1830 when he arrived back from Rome. The library was created to house part of the library impounded by the French state in 1789. Consists of a perimeter wall of books enclosing a rectilinear space and supporting an iron framed, barrel vaulted roof which is divided into two halves and further supported in the Centre of the space by a line of iron columns. The style was called Structural Rationalism.

There are 19 regularly spaced arches. Only the upper portion is glazed, allowing light to penetrate the second storey reading room, measuring 17 by 80.75 meters. The building, although essentially hiding the use of iron on the interior, makes good use of repetitive elements and quicker assembly processes for the construction of the iron members.

Henri Labrouste. Biblioteque National. 1857-67:
Inserted in the courtyard of the Palais Mazarin, it consists of a reading room covered by an iron and glass roof carried on 16 12-inch diameter cast iron columns and a multi storey wrought and cast iron book stack. The reading room is top lit as well as the stacks, the light filtering down through iron landings to the bottom floor. The nine identical domes are 10.5 meters in diameter. Columns are 10 meters high. Columns are joined by wrought iron arches built up of plates and angles. The skeleton of each dome is composed of a series of arched wrought iron meridians in T sections, joined by concentric circumferential ribs. White enameled panels fill the spaces between the metal tracery. It was unusual as it exposed iron as a material in a permanent public building.

V. JOSEPH PAXTON AND THE CRYSTAL PALACE: THE PROCESS OF INDUSTRIALIZATION APPLIED TO DESIGN AND CONSTRUCTION

"In contemplating the first great building which was not of solid masonry, spectators were not slow to realize that here the standards by which architecture had hitherto been judged no longer held good." E.L.Bucher

"An entirely novel order of architecture, producing by means of unrivaled mechanical ingenuity, the most marvelous and beautiful effects, sprang into existence to provide a building." The London Times

The Crystal Palace was one of the most influential buildings ever erected, innovative in its structure, unusual in its form and completely new in its function. Victorians saw the Crystal Palace not as architecture but as construction--anticipatory of the factory aesthetic of the early 20th Century. design by Joseph Paxton in 1851 responded to design outline for the exhibition building: to be temporary in nature, economical of materials and labor, simple in arrangement, capable of rapid erection, dismantling and expansion, illuminated, built of fire resistant materials and erected over an 18 acre site mostly to a height of one storey the outline in fact could not have been filled by contemporary, usual methods of construction.

The building design was simple: it consisted of a series of hollow cast iron columns joined by trussed girders that supported planar roof made of glass panes in a pleated, ridge and furrow configuration. The components of this system included base plates for the columns, projecting about four inches above the floor; the columns rising approximately 18 1/2 feet above the plates; connecting pieces, extending a bit less than 3 1/2 feet to provide a junction of columns and girder, and six inch deep gutters at eight foot centers supporting sash bars that held in place on an incline of 2.5:1. These held sheets of glass each measuring 10 x 4 inches. The plan module was based on 24 feet, with bays of 24 feet, 48 feet or 72 feet. The module of the building was based on the maximum glass size manufacturable at the time in the thickness required (10 x 49 inches); therefore, eight modules plus mullions equaling eight feet; three times eight feet equalling 24 feet. There were as well, diagonal bracing rods, 7/8 and 3/4 inch in diameter with tightening rings in the Centre to give lateral stability to the structure. This was a critical structural innovation as this new light structural type, based on framing techniques, lacked the traditional mass that had resulted in stabilization. The structural stability also relied on the invention of portal bracing or framing (bracing at depth of top connecting member which gives lateral wind stability by counteracting the rotation at the ends of the beam that would normally occur if the beam rested on top of the columns).

The Crystal Palace design utilized industrialized processes for manufacturing the components of the building; all cast iron columns, bases and top girder connecting members were identical. The wooden pieces were run through one step milling machines There was dip trough for prepainting wooden trim. The four columns and girders comprising one bay could be erected in 20 minutes as all connections were bolted for quick assembly and easy dismantling. The hoarding around the site was precut in sizes (1 x 8 feet) reusable as flooring for the gallery viewing spaces. Paxton also invented glazing trolleys which ran in the gutters to facilitate glazing under cover without need of scaffolding.

Paxton used new innovations and discoveries in truss technology. He used cast iron for the shorter spans and wrought iron for the longer spans due to their different structural strength. He swelled out the thickness of the members at the Centre of the span to take the higher bending stresses on the cast iron members. He riveted extra bars to the central section of the wrought iron trusses to take the extra stress. The truss form used much less material, making the sections lighter and more economical.

Paxton used prestressing in wooden gutters to prevent sag by attaching wrought iron rods to the underneath side and tightening them in order to have all the trusses the same depth to facilitate quick erection (all were three feet deep). They cambered the sections so that they would deflect but not sag. The 72-foot span sections were cambered 10 inches.

The building was able to be designed and constructed in 39 weeks, including painting all the structural members key different colours (actual assembly taking only 17 weeks). It was able to be disassembled, moved and re-erected at a later date. Glass that was damaged during disassembly was melted down and re-blown. More columns and iron sections were cast and the building shape changed slightly and was made larger -- proving the adaptability of the industrialized technique.

VI. THE INVENTION OF STEEL AND ITS EFFECTS ON DESIGN:

The invention of the Bessemer converter in 1867 allowed for the use of steel in building. This is a process for making steel by blowing air through molten pig iron contained in a suitable vessel, and thus causing rapid oxidation mainly of silicon and carbon. Pig iron is the iron produced by the reduction of iron ore in the blast furnace. Steel is an iron base alloy, malleable in some temperature range as initially cast, containing manganese, usually carbon, and often other alloying elements. In carbon steel and low alloy steel, the maximum carbon is about 2.0%; in high alloy steel about 2.5%. The dividing line between high and low alloy steels is generally regarded as being about 5% metallic alloying elements. Steel is to be differentiated from two general classes of 'irons': the cast iron on the high carbon side, and the relatively pure irons, on the low carbon side.

The invention of Bessemer converter (1867) enabled the construction in 1873 by Jules Saulnier of build the first building with a steel skeleton, the Menier factory at Noisiel-sur-Marne.

VII. THE UNIVERSAL EXHIBITIONS:

Exhibitions of industrial products reflected the direct relationship between the manufacturers, the wholesale dealers and the consumers (after abolition of the guilds). There was a relaxation of controls on foreign trade 1851: The Crystal Palace idea of temporary structure that could be disassembled after the exhibition and whose pieces could be reused.

Temporary exhibition buildings had completely new design requirements. They needed to be of a temporary nature, able to be constructed quickly and usually demounted. Much of the material was to be recovered. This resulted in an economy of the plan: complete prefabrication, rapid assemblage. The possibility of recovering costs and technical experience caused a new relationship to be established between the technical means and the desire for prestige and the expressive aims of the building. The smallness of single architectural elements resulted in a composition based on the repetition of a single architectural motif. These buildings outwardly resembled models of the neoclassical tradition, although they established new tradition/example to be followed for ensuing international exhibitions in Austria, France, etc.

Paris: World Exhibition 1889:

Galerie des Machines (Krantz and Eiffel)
Galerie des Machines 1899 used new type of arch (ogee) with multi hinges to create span--endlessly repetitive module and structure.

Galleries des Machines. Charles Dutert architect and V. Contamin engineer. 1887-9.
Destroyed in 1910. Building measured 115 by 420 meters, supported by three hinged arches. Two mobile trolleys installed to facilitate movement along the length of the building.

Gustave Eiffel (1832-1923): Eiffel Tower. Paris 1884-9:
1000 foot high parabolic vault. Sits at the termination of the axis on the Champ de Mars. Made of 15,000 prefabricated steel parts. Four inclined elevator systems serve the 200 foot level with

two more continuing the relay to the 370 foot level. Another shuttle carried the visitors to the apex (served 2,350 visitors an hour). The guide rails for the elevators were used for the climbing cranes that were used to erect the building.

Horizontal forces diagram. "The first principle of architectural aesthetics prescribes that the essential lines of a building should be perfectly suited to its purpose. And what laws have I had to take into account with the Tower? Resistance to wind. Well, I believe that the curves of the four outer ribs, as calculation has determined them .... will give a great impression of strength and beauty, because they will convey to the sight the boldness of the whole construction, in the same way that the numerous empty spaces contained within the elements themselves will firmly stress the constant concern not to offer to the violence of high winds, surfaces dangerous to the stability of the building."

Many of the large exhibition buildings took on the structural challenge of span. By the end of the century, iron buildings had reached the limit of their possibilities (Lyon exhibition 1894 boasting a dome span of 110 meters).

The effect of the construction of the Crystal Palace on its contemporary architecture was immediate. It gave rise to a new 'type' of building--that housing the international exhibition.
A phrase was coined 'of Crystal Palace construction'. This referred to glass arcaded buildings. This led directly to French and German department stores of iron and glass construction. This was a direct precursor to contemporary curtain wall construction.

Viollet-le-Duc's criticism of Beaux Arts in 1861:
"In our time, the budding architect is a boy of fifteen to eighteen ... who, for six or eight years, is made to make plans of buildings which usually have only distant connections with the needs and habits of our own times, and which never have to be practicable; he is never given any knowledge, however superficial of the materials at our disposal, of their use, never taught about the building methods used in all known ages, never given the slightest idea of the conduct and administration of practical work" Benevolo p. 120

There was a growing feeling that architects could no longer be regarded as mere artists. It was felt that they had to define their professional function and to have at least enough scientific education to be able to collaborate with engineers.

VIII. REASONS FOR DISCONTINUITY IN THE INDUSTRIALIZED MOVEMENT:

In spite of the successes of the buildings of the industrial exhibitions, this failed to generate a movement that might be recognized as a new style of architecture. The wholesale applications of the Crystal Palace methods were not applicable to most of structures to immediately follow. Few other buildings were of the same scale, intentionally given a limited life span. Speed of construction and impermanence and flexibility were not deemed as important. Iron and glass were able to be used in other buildings without the adoption of the entire assembly method.

However, when in fact buildings were not considered to be fully 'industrialized' as was the Crystal Palace, the RATIONALIZATION of building design and construction had begun and gained a strong foothold in the construction of commercial and industrial buildings. The era of high-rise skyscrapers, advanced by those such as Burnham and Root, and William Le Baron Jenney, made use of repetition in construction and the use of "standard" steel sections. As well, department store facades and structures made use of repetitive cast iron fronts and building structures. Therefore, although Paxton did not continue to be copied verbatim, his rationalized techniques did gain much favor due to economic criterion.

Rapid progress was made in the later decades of the 19C in the invention of reinforced concrete. The new building codes preferred reinforced concrete for fire reasons. This led to much scientific explorations in reinforced concrete construction, types and systems of reinforcing, monolithic construction -- and relative abandonment of steel construction and methods of assembling buildings as opposed to wet process. Hand crafted buildings--which were undoubtedly more appealing to eclectic design in the closer relationship with stone and masonry construction than steel (a gross generalization for the purpose of jumping a few years).

IX. HOUSING: STANDARDIZATION AND PREFABRICATION:

a. The Modern Movement and Standardization:

The emergence and acceptance of standardization in the design of buildings, planning and components was necessary for the continuance of assembled and rationalized architecture. Residential buildings were needed in great quantities and a rationalized and repetitive method of building was the only means to keep up to demand.

The Chicago Apartment House of 1891 and Catherine Beecher's 1869 plan of a city flat and the section of a 1930's apartment with stacked plumbing illustrate the development of this type of rationalized planning--from structure to services.

b. Initial concepts for prefabrication in housing:

Le Corbusier. Maison Domino 1914:
"In the next twenty years, big industry will have coordinated its standardized materials ... technical achievements will have caused... methods of rational construction far beyond anything we are acquainted with".

A precast concrete building system of 1912 shows the beginnings of transformation of reinforced concrete systems, which are site labor intensive, into assembly structure.

Richard Neutra (1892-1970) One Plus Two prefabricated extendible family house 1926:
Shows an early system for an assembled dwelling that looks at repetitive design of the structure as a means to create many houses from the same base parts, though of varying size. The every asked design question (for the ego of the Architect...) how do I make many, not the same, but different?

Walter Gropius (1883-1969):

A return to the use of steel and industrialized processes was 'initiated' by the Deutsche Werkbund (1907): "The aim of the Werkbund [said the statute] was to ennoble craftsmanship, electing the best representatives of art, industry, crafts and trades, combining all existing efforts towards quality in industrial work, and forming a rallying point for all those who are able and willing to work for quality".

"The difference between industry and craftsmanship is due far less to the different nature of the tools employed in each, than to sub-division of labor in the one and undivided control by a single workman in the other. This compulsory restriction of personal initiative is the threatening cultural danger of the present day form of industry. The only remedy is a completely changed attitude towards work, which though based on the sensible realization that the development of technique has shown how a collective form of labor can lead humanity to greater total efficiency than the autocratic labor of the isolated individual, should not detract from the power and importance of personal effort." Gropius

Gropius and Wachmann: Details of the packaged house system 1942

Le Corbusier: Le Modulor (1945):
The search for an idealized rationale behind modularity in design and construction. The need for rationalized rules for design. Although not directly used on assembled architecture to follow, Le Corbusier’s system represents some of the beginnings of rationalized thought process. Le Modulor looked for a proportioning system, based on the perfection of the Golden Section, combined with the dimensions of human habitation.

Le Corbusier: Unite d'Habitation Marseilles (1945):
Unite was designed using the Le Modulor proportioning system. This represents the beginnings of the idea of the dwelling cell -- Megastructure ideas whereby the structural framework for residential high-density housing would be erected and then units attached as needed. Not actually implemented in the Unite.

James Stirling (1926-): Maison Domino (1953):
Housing directly based on Corb's Maison Domino, only Stirling's model was repetitive, attachable and included a prefabricated cladding system, which Corb's did not. Both were proposed to be constructed of precast concrete structural systems.

Standard Prefabricated houses:
These were available to the common person and achieved the kind of widespread use/production only possible if a large enough market could be cornered for supply (economic factors).

A new interest in steel construction vs. reinforced concrete construction in the school of thought following Mies. The speed of construction was becoming ever more important. Cold weather construction was impeding reinforced concrete construction. The nature of the constructed reinforced concrete building was unchangeable. Flexibility was becoming an important idea that began to favor the demountability of assembled steel construction. It was also recognized that costs could be cut if more work was factory done. Factory labor is significantly less costly than wet, site work, and also achieved under environmentally controlled and better supervised conditions -- resulting in higher quality of product.

Charles Eames (1907-1978) Eames House, Santa Monica, California (1949):
The building was assembled from standard parts and composed in a sensitive irregularity that reflected an interest in Japanese wood frame construction. The aesthetic affect arose from the careful juxtaposition of ready-made elements. In the same period in California the case study houses by Ellwood and others showed how ideas of standardization could be employed to create extremely specific landscape responses.

c. The house as a prefabricated cell:

Buckminster Fuller (1895-): Prefabricated Bathroom Unit (1938-40):
Prefabricated unit housing; apartments; stacking units

Moshe Safdie (1938-): Habitat, Expo 1967:
The idea of the cellular dwelling able to be prefabricated and assembled on site quickly, yet allowing modifications. Unfortunately ended up taking longer than standard building methods and costing a great deal more due to the degree of specialization required in adapting the 'standard' unit to rotation. All wiring and services were contained within the walls.

Kisho Kurokawa: Taisei Overseas System, Design Prototype, 1971:
Closed system of prefabricated precast concrete parts.

Kisho Kurokawa: Nakagin Capsule Building (1972):
Based on outer space precedents, is a total living environment attached to a service core. In a space approximately 8 ft x 12 ft there is a complete bathroom, double bed, HVAC unit, desk, chair, storage space and convertible kitchen area. Equivalent to a standard six tatami mat room, this small area is not uncommon for bachelors and some young married couples.

Kisho Kurokawa: LC-30X Leisure Capsule (1972):
A logical evolution of the Nakagin Capsule, this capsule cluster combines a service module, sleeping module and living module.

Katsuhiko Ohno: Sekisui Haim (1973):
The manufacturing plant, modeled after an automobile assembly line produces one box unit every five minutes. A typical three bedroom house employing seven or eight box units can be assembled in three hours, not including foundations, caulking and finishing. The company is now offering the box unit houses in 20 variations, and as technology becomes more sophisticated the options will expand.

Alvin Toffler (author of Future Shock):
"The more advanced the technology, the cheaper it is to introduce variation in output. We can safely predict, therefore, that when the construction industry catches up with manufacture in technological sophistication, gas stations, airports and hotels, as well as supermarkets, will stop looking as if they had been poured from the same mold. Uniformity will give way to diversity."

Marshall McLuhan:
"When automated electronic production reaches full potential, it will be just as cheap to turn out a million differing objects as a million exact duplicates. The only limits on production and consumption will be the human imagination."

X. THE EMERGENCE OF BRITISH HIGH TECH ARCHITECTURE:

a. The Beginnings:

The use of steel in prefabricated architecture grew again in interest during the movements of the 1960's in Great Britain. Architects were taking interest in the technological approach as espoused but not actually practiced or built by Archigram and others--as practiced by Norman and Wendy Foster, Richard and Sue Rogers, Michael Hopkins, Arup Associates and Farrel and Grimshaw, etc. Architects interested in the technological approach as it led to buildable architecture also grew from movements by Ezra Ehrenkrantz and, CLASP (Consortium of Local Authorities School Program), SCSD, etc. (industrialized building).

Assembled building constructed from steel framing is currently possible for types of uses only requiring up to a1 hour fire rating. Although steel is normally only used for up to a 3/4 hour rating, more applications are possible due to new paint like intumescent coating with a 1 hour rating (paint expands into fire resistant foam when exposed to high temperature). This coating is more expensive than paint, but saves the cost of painting (as it can come in any color), strapping and drywalling. It is currently under ULC testing for 2-hour usage, which if possible, could revolutionize the construction industry.

Team 4 (Norman and Wendy Foster and Richard Rogers): Reliance Controls Factory, Swindon (1968):
The emergence of the idea of the serviced shed.

Michael Hopkins: Hopkins Residence, Hamstead (1977):
Illustrates the concept of a factory or neutral enclosure. Planned on two floors with a circular staircase near the Centre of the house, only the bathrooms and a store are enclosed by fixed partitions. Elsewhere, the family's activities are defined by venetian blinds. Flanked by side walls in profiled heavily insulated steel decking, the structure is a simple steel frame with exposed lattice beams, supported internally on steel columns on a 2 x 4 m grid. It was cheap, composed of small structural members and very thin framing details and constructed from a very limited range of materials.

James Stirling: Southgate Housing, Runcorn New Town (1972-77):

High tech or assemblage architectural design requires a reassessment of the role of the architect:
Piano: "One of my deepest convictions is that the architect should design his own working instruments, his technical and disciplinary equipment. This is a sort of return to one's origins that is further justified today in the light of conventionalism and mass production of the conceptual process. If one does not intervene in the making of instruments, in its processes, we risk having

our work relegated to the periphery where there is only space for ineffective and nostalgic operations." Designing means building and the various fields of expertise have to be recombined and the roles in the creative process integrated.

b. Differentiation: The Architecture of Assembly (High Tech) vs. Industrialized Building

The Architecture of Assembly or as it is called commonly, High Tech Architecture, grew out of the marriage of the modern movement in architecture with an interest in industrialized building practices as developed, (for example, by the CLASP team) and with the ideas and design practices of Industrial Design although assemblage practices are common to both types of architecture, Industrialized Building seems to put engineering practices and cost above design and aesthetics. The Architecture of Assembly consciously uses the industrialized parts as the architectural form and expression of the building, texture, vitality -- going so far as to design some of the significant systems (at greater cost). The Architecture of Assembly treats both the systems (structural, mechanical and electrical) and connections as the sense of the architecture of the building, raising the design of the systems beyond efficient assemblage

There are two categories of Architecture of Assembly (if one must generalize and categorize): the first uses more systems of specially designed parts and can be subdivided into Gothic (exposed structure -- more blatant), and Classical (less exposed structure--calmer and more repetition of parts); the second which generally uses off the shelf parts, to be complimented on occasion by specials (usually in the industrial design detailing of the assembly).

The use of color in the building is very important. The keying of the various systems by color-coding is reminiscent of the painting of the Crystal Palace as designed by Alhambra Jones. Jones used a system of colours for horizontal members and the flat, concave or convex surfaces of the vertical elements. Usually a choice is made between painting up the structure or mechanical systems (ducts). Where the mechanical system is highlighted, the structure is often white. This depends on the appropriateness, character and intent of building and use or not of steel.

I basically object to the term "High Tech" as the technology used in the architecture of Assembly is appropriate and current technology -- NASA uses high technology. The choice of technology is implicit in the choice to build.

c. The Buildings and the Players:

<u>i. Renzo Piano:</u>

Piano feels that the High Tech label has been too hastily attached to his work.
"The choice of technology is implicit in the choice to build. Even the use of stone corresponds to a precise technological option. It is simply that in an advanced period like our own materials are available with high levels of cohesion and durability that are easily worked and handled. It is culturally a mistake to reject the opportunity to mold an architectural language using all this

potential. It is questionable even to make an issue of it. An architect, a builder, cannot help but use technological methods when it meets the design requirements." Piano.

Piano seeks to progress beyond the clash between creativity and science. The technological instruments are varied, complex and continually evolving; mastering them calls for a very high level of competence. The problem is to dissect and memorize the structural factors. The visible aspects of constructional processes begin from scratch with matter and its laws and biotechnological images. Naturalistic form inspires the engineering solutions.

Centre Pompidou: Piano and Rogers (1972):
Controversy: Why translate culture into the language of High Tech? What is the point of grafting a science fiction machine onto the urban fabric: Why emphasize technology without bothering to connect it organically with the environmental setting?
"...it is not a triumphant building. In fact, I would say it displays a certain sense of humor; one might even call it a joke. Far from being a triumph of technology, the Beaubourg is not even an industrial building. If anything, it is a gigantic piece of craftsmanship, made by hand, bit by bit, a great prototype. There is the relish for the polemical, the provocative, the sending up of the accepted idea of the museum and what it is meant to be. At the start of the seventies we were at a crossroad, we had to choose between two different concepts of culture: either institutional, esoteric, intimidating or something unofficial, open and accessible to the general public. We opted for the latter." Piano.

The Centre Pompidou represents the highest order of Reyner Banham's "serviced shed":
"It is typical of the fundamental conservativism of British Patrons that the most highly wrought of the big sheds should be by British designers but carried out for a Parisian client, the French government ... the Pompidou Center is a big shed inside out: six large clear floors enclosed by a glass skin but with all the structures and service runs and most of the circulation outside...deploys both sensational structure, brightly colored vertical air conditioning stacks and ad hoc walkways in a gesture towards flexibility." Lyall.

"The fact that it is becoming a functional or even a formal architectural model is tragic and absurd. If anything is worth copying it is the design procedure, the scientific approach, the technical research. What its immensity conceals is craftsmanship. We designed everything, right down to the smallest screw." Piano.

Exemplary of this design aspect is the design of the ‘gerberettes' (single casting of 11 tonnes of steel) prefabricated components to maximum size for assembly.

The IBM Traveling Exhibition:
This is an exhibition building to house a traveling show that would explain the capabilities of contemporary computers to schoolchildren and students. IBM wanted to rid computers of the "High Tech" image -- convey them as a normal part of everyday life -- so they decided to have the show in city parks. The building is a demountable timber and polycarbonate structure (Piano's Soft Tech approach to prefabricated architecture). The structure is based on a series of three pinned freestanding arches; each half arch has a top chord of laminated timber, bottom chord of a ladder like laminated timber with the web being formed by the pyramidal

polycarbonate material. The gaps between the arches is covered by PVC gaskets. The building sets down on adjustable feet to accommodate the uneven ground of parks.

The floor is raised to house mechanical equipment beneath which supplies conditioned air to the central duct that blows air down the arch to prevent condensation. Plants are situated to hide the air conditioning units. Within the structure there are employed a variety of methods of controlling solar glare which fit into the arches. Two exhibit buildings were constructed so that one could be serviced and placed while other was dismantled and transported to next show site.

ii. Foster Associates:

"It becomes increasingly clear that the distinguishing feature of modern corporate clients is less that they are faceless, or bureaucratic, but that they can count. They are numerate and measure architectural quality in figures. The architect who makes them promises must be able to deliver in measurable quantities ... Foster always thrives in these close-counting circumstances." Banham.

Foster's pedagogy relies on the use of "appropriate technology": "lesson of building history is not that one particular type of construction is superior or less wasteful or more natural than others, but that many modes of construction have long been understood to be subtly more appropriate do different sorts and conditions of buildings and that you cannot tell which is the more appropriate by looking--the proof is in the performance."

Their work is not stylistically unified but draws from a series of master concepts: the glass box, the metal shed, the downtown polygon... consistent in fastidious, elegant but conspicuously minimalist detailing highest technology and energy efficiency in the design of the skin -- versions of curtain wall construction.

Foster feels that the building is an integration of systems rooted in social and technical research. The systems range from structural, mechanical and electrical (traditional) to interior systems. He is concerned with flexibility and change in movement. He thinks that energy is a servant not a master and is there to be used effectively and efficiently.

Sainsbury Centre (1977):
This piece marked the return to the shed type of building that was designed as a logical build-up of separable elements. The structure was formed of specially designed triangular trusses that were repeated for the length of the structure. The skin was of two types: system of three different types of panels for three different purposes carried on subframes that are bolted to the main structure, and mullionless glass wall. It was a complex skin for the side walls and roof, and a simple skin for the end conditions. There was flexibility in the positioning of the panels on the exterior of the building (can be interchanged in minutes) needing only six bolts for installation. The solid panels are highly reflective with an insulating core with an outer skin molded of superplastic aluminum (an alloy that at a given temperature can be stretched and molded to very fine tolerances). The panels are combined with a motorized bank of louvers to give total flexibility in the amount of natural lighting. The interior is a clear span for flexibility in the use of the space. The building components used advanced manufacturing processes in aluminum, steel, glass and neoprene. The clear span structure is sandwiched between an external panel system and an internal skin of louvers. The service spaces are located within the vertical structure on the exterior of the building to give internal floor plan flexibility.

The lack of color on the interior is deemed appropriate for the use as museum -- a backdrop for exhibits.

iii. Richard Rogers:

Inmos: South Wales

PA Technology: Hightstown, New Jersey: with Kelbaugh and Lee of Princeton, New Jersey
The flexible well serviced shed motif was employed for this building (Reyner Banham). The architects restricted themselves to Princeton off the shelf items and workshop welding as custom construction was prohibitively expensive in the US. The building came in at $110 per square foot. The project required integration of the engineer into the design process. This follows Rogers' belief that architects must regain control of the production process if they are to reassert their traditional, primary role in the building process. He believes that architects belong in the laboratory and the workshop where technical innovations and refinements take place that can advance the art of building.

The thrust of the design is to maximize the column free space. This is accomplished by means of a tubular steel tension structure. The structural system is a portal frame that supports in piggyback fashion an A frame, from which are suspended standard section steel beams, spanning 75 feet to either side of the central spine. The A frames are 30 feet on Centre. The platforms on the A frames support all mechanical equipment. Virtually all elements are off the shelf except the pin-ended columns. Field welding was kept to a minimum and pin connections (bolted) were used wherever possible.

iv. IKOY Architects, Winnipeg, Manitoba:

Industrialization as applied to IKOY is postulated as the rationalization of production in which complex tasks are reduced to simple ones, that, gathered together, produce complex products in large quantities. IKOY considers the architect as a master of assembly as opposed to master builders. Designers should actively use all parts of the building as architectural expression. The building should be demystified for its users, and express the excitement inherent in a vibrant, functioning, lived-in machine. A building must be designed in recognition of the skills of the labor force that will manufacture and construct it.

The key to efficient economic design and construction is to realize that buildings consist of only six components, rather than a collection of details. Architecture is made by designing these component parts to perform their functions to meet the needs of the most essential building component -- the people within the building.

1. Planning System (now dropped and they profess only 5)
2. Structural System
3. Mechanical System
4. Electrical System
5. Skin (or enclosure)
6. Fitments

Some of the systems include both elements that are primary and rarely moveable and elements that are secondary, moveable and easily changeable.

The design process sees the engineering systems as architectural systems and an original part of the architectural concept of the building (to avoid imposition of these systems on the architecture as is customary). This necessitates architectural design input into the design of the visual aspect of the engineering systems. Connections, etc. need to have industrial design applied. The firm sees the architect as a purchasing agent for assembled parts.

The same assembly techniques cannot be used on all buildings. The process calls for all building joinery to take place in the factory under supervised controlled conditions, with on site assembly. 90% of their work is factory pre-assembled, designing around the remaining 10%. The potential for error is reduced by minimizing the number of parts.

They see building as a living thing and do not expose innards for sake of exposure. If the parts are attached to the building so that they express their reason for being there, a different texture results with a purpose beyond decoration.

Structural and Planning Systems:
Structure is the generating matrix. The planning system needs to accommodate the movement of people. Span selection is crucial; short spans being seen as light and dynamic, not an encumbrance. They do not use poured in place concrete or other wet structure in the buildings, with the exception of grout for precast concrete. In general they use precast concrete hollow core planks for floor slabs.

Mechanical Systems:
They ideally see the design of an integrated system of a series of factory made modular units. These are to be delivered by truck and craned into place, making connection of ductwork simpler and faster. The design would accommodate retrofit and upgrading of system.

Electrical Systems:
The architects locate transformers so that they can be moved. Switching gear and raceways run exposed in main corridors which are the spines of the planning system so you can tap into them for any power that is needed for room functions. There are no wires in the partitions; maximum factory wiring.

Production Drawings:
In the mid 1980's the firm used the multigraph system. This is an overlay system where each of the six component systems is a separate section of the contract drawings, consisting of several overlays, plus several drawings showing the connection and integration of the components. The system uses four-color printing plus halftones to emphasize the building systems. The same approach has been perfected in CAD systems.

Red River Community College Automotive Diesel Shop:
The design explores the idea of transparency and difference in view at various times of the day (depending on light differential from inside to outside). IKOY uses transparency to give depth beyond the skin of the building. The exo structure is permissible at the truck vestibule entrance. The structural system and electrical raceways are colored to give added texture and vibrancy to the structure. Freestanding mechanical and electrical equipment are used as spatial interest. There is a difference in material treatment of crane/repair bay with classrooms. The firm is strongly against the use of gypsum board as it us not sturdy enough for industrial and institutional purposes. The use of concrete block is limited as it is not easily changed (inflexible).

Earth Sciences Building, University of Manitoba:
This building is constructed from a system of precast concrete columns and beams and hollow core concrete slabs. It is the precursor to the Davis Center at the University of Waterloo. The skin and mechanical systems are to be painted (contrasting with the color of the exposed concrete material). The idea of transparency is used at the entrances (structure seen behind gives depth to the facade). The hollow core concrete is also used as an extension of the ductwork. The external wall system is that of control grid -- allowing random placement of glazing where needed in a controlled system.

XI. SUMMARY OF THE IDEAL INTENTIONS OF THE ARCHITECTURE OF ASSEMBLY:

The Architecture of Assembly is a type of industrialization as applied to architecture that strives for the maximum amount of factory manufacture and preparation of components for on site assembly. It looks to a minimalization of wet process on site. It focuses on the design of and with a series of systems, structural, mechanical and electrical that are interrelated. These systems are relied on for architectural expression. The nature of design for assembly results in repetition of elements of design; the use of color to highlight and differentiate systems; the possibility for flexibility; the conscious use of technology in the creation of the structural system; and, energy efficiency of skin and other systems. The use of "appropriate technology" vs. soft or high/hard technology.

The system uses modularity and dimensional coordination in the planning of the architectural and structural components of the building, as well as the skin. There is importance placed on the architectural, structural and environmental quality of the joints in the structure and the building envelope in preparation for 'assemblage'.

XII. CURRENT DESIGN METHODOLOGY:

a. The Principles of Modular Coordination in Building:

Danish Building Research Institute: The International Modular Group, 1984.

Principle Objective: to provide a practical and coherent method for the coordination of the position and dimensions of elements, components and spaces in building design.

Means of Achievement: By the application of the internationally agreed 100 mm module to the sizing of building components, etc. By the development of an agreed terminology. By stating a set of interrelated concepts, which comprise the general principles of modular coordination.

Dimensional Coordination: A convention for the coordination of the dimensions of building components and the buildings incorporating them, for their design, manufacture and assembly.

Modular Coordination: Dimensional coordination employing the basic module (100 mm) or some whole multiple thereof.

All systems are based in the three dimensional reference system.

b. National Standard of Canada: Series of Standards for Metric Dimensional Coordination in Building, CAN3-A31.M-75, 1975:

Reference Space Grid: means a three dimensional system of reference planes.

Modular Space Grid: means a reference space grid in which the distance between consecutive planes is the basic module or a multi module. This multi module may differ for each of the three dimensions of the space grid.

Modular Coordination is intended:

- to facilitate cooperation between designers, manufacturers, distributors and contractors
- to permit the use of components of standard sizes in the construction of different types of buildings
- in design work, to simplify the preparation of drawings by making it possible to determine the dimensions of each component and its position in relation to other components and to the building as a whole
- to reduce to the optimum the number of standardized sizes of components
- to permit the interchangeability of these components, whatever their material, form or method of manufacture
- to simplify site operations by rationalizing setting out, positioning and assembly of components in order to reduce adjustment, wastage and the time needed for their erection to a minimum
- to ensure that any component or system installed in the building is dimensionally coordinated with all other adjacent or facing components or systems and the building itself